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DESIGN, TEST, AND DOCUMENTATION OF THE MARC 36A1, 1-KS-75 SPIN MOTOR FOR THE SCOUT VEHICLES

Prepared under Contract No. NAS 1-3899 Task 18 *by*
ATLANTIC RESEARCH CORPORATION
Alexandria, Va.
for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION - WASHINGTON, D. C. - JANUARY 1966

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

This is the final report covering the design, test, and documentation of a 1-KS-75 spin motor for the Scout vehicle. The program was authorized under Purchase Order P-110534 AER from the Vought Astronautics Division of Ling-Temco-Vought, Inc. The date of contract effectivity and program inception was January 29, 1965. All test work was completed by May 31, 1965.

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1. SUMMARY

The MARC 36A1, 1-KS-75 control rocket was designed and tested to demonstrate its suitability for use as a spin motor on the Scout space probes. Grain design and motor ballistics were verified in a series of 35 heavywall motor firings. Twenty-four flightweight motors were then static-fired to conclude a formal nine-motor development program and a 15-motor Preflight Rating (PFRT) program. Six of the PFRT motors were subjected to environmental tests of vibration, shock, acceleration, and drop before firing. Four of these six units were specifically designated as Qualification Test motors; the other two, having discrepant propellant weights, were designated as backup environmental test units.

The high-impulse performance required of the MARC 36A1 motor was achieved with a high-energy aluminized plastisol propellant, extruded in a key-hole grain configuration affording a high loading density. Burning rate problems encountered early in heavywall development were resolved through tight control of the propellant's weighted average oxidizer particle size. The original nylon-epoxy inhibitor was replaced with an epoxy-impregnated cotton sleeve to prevent inhibitor breakup and discharge during motor operation. To prevent overheating of the flightweight motor case, a rubber-based insulating barrier was later added over the keyway slot in the grain.

At the end of heavywall development, the only ballistic parameter failing to meet its design criteria was progressivity ratio. Ratios below the 1.3-maximum limit, however, were consistently obtained in flightweight motors. All PFRT ballistic data were within specification limits, except for random ignition thrust values in excess of 70 pounds. The motor was accepted for service use on the basis of Qualification and PFRT test results.

2. MOTOR DESIGN

2.1 GENERAL DESCRIPTION

The MARC 36A1 solid-propellant control rocket is used for applying spin forces to the fourth stage and payload of NASA's Scout and the Air Force's Blue Scout space probes. Fully assembled, the motor weighs 0.85 pound and measures 6.86 inches in over-all length and 1.53 inches in outside diameter. At 77°F and vacuum, it burns for approximately 1.0 second, delivering a total impulse of more than 75 pound-seconds. A photograph of an assembled MARC 36A1 rocket is presented in Figure 1; a cross sectional schematic is shown in Figure 2.

2.2 PROPELLANT GRAIN

2.2.1 Propellant Formulation

The MARC 36A1 rocket motor uses a proven aluminized plastisol composite propellant, Arcite 427B, to provide the high energy required for specification performance. This propellant delivers a vacuum specific impulse of 258 lb-sec/lb with a nozzle expansion ratio of 21.3 and a chamber pressure of 950 psia. Thermodynamic and physical properties of Arcite 427B are presented in Table I.

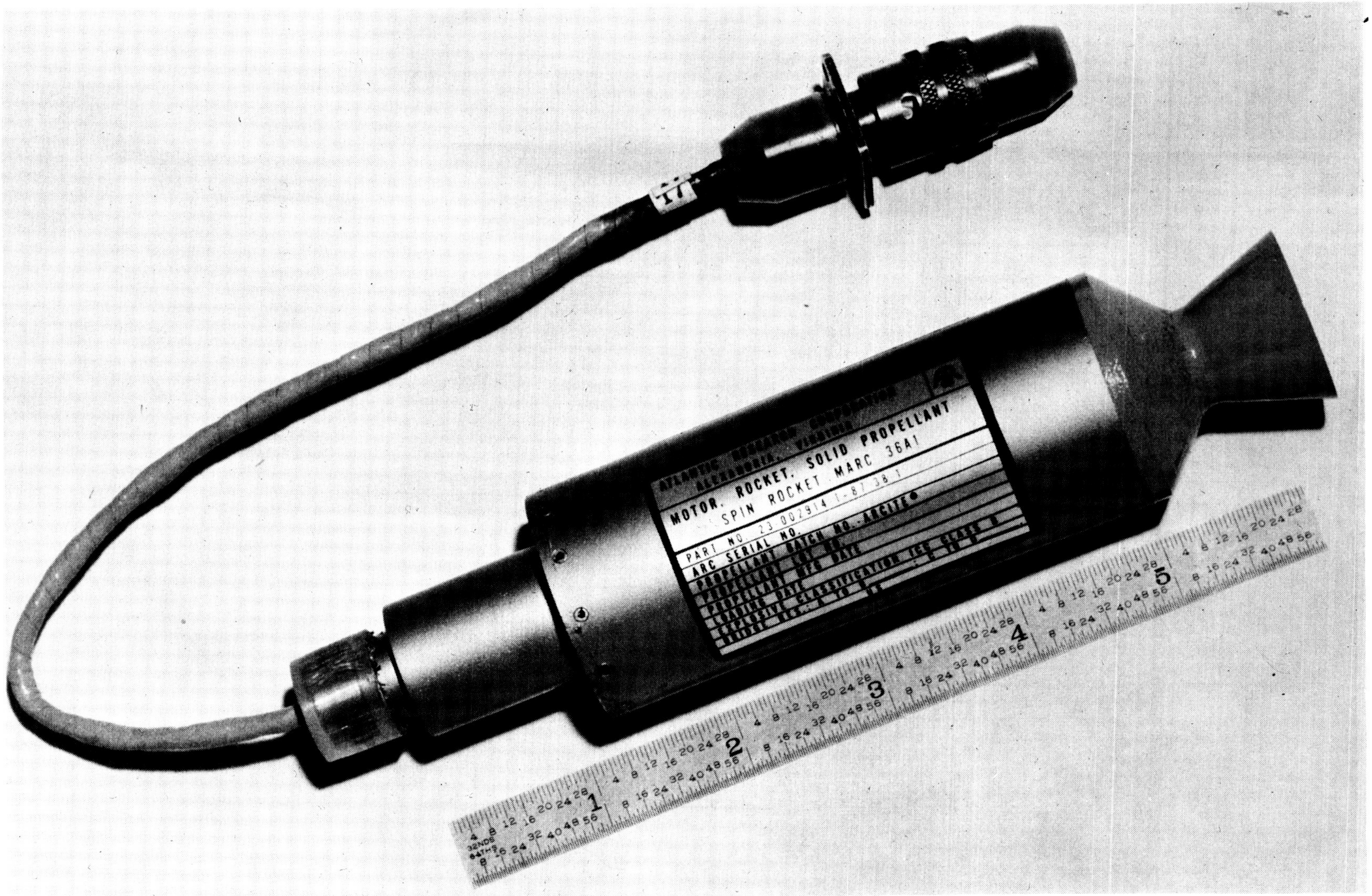

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Figure 1. MARC 36A1 1-KS-75 Scout Spin Motor.

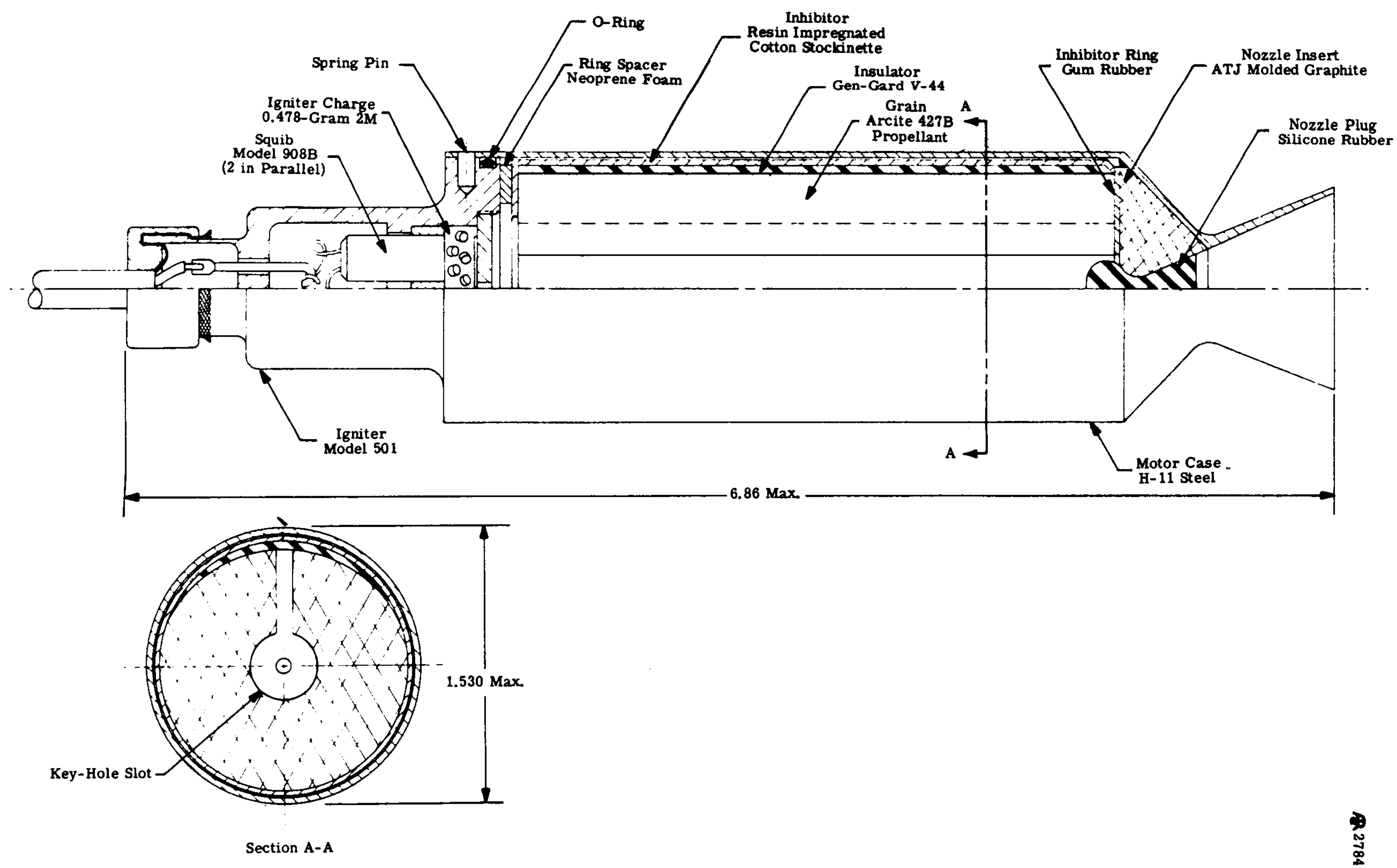

Figure 2. Cross Sectional View of MARC 36A1 Rocket Motor.

Table I

Properties of Arcite 427B Propellant

Thermodynamic Properties	
Theoretical Specific Impulse (1000 → 14.7 psia), lb-sec/lb	258.7
Theoretical Vacuum Specific Impulse (ϵ= 10.8), lb-sec/lb	283.6
Ratio of Specific Heats	1.181
Theoretical Discharge Coefficient, lb/lb-sec	0.00642
Flame Temperature, Chamber, °K	3398
Flame Temperature, Exhaust, °K	2238
Physical Properties	
Density, lb/cu. in.	0.0646
Ultimate Tensile Strength, psi	81
Ultimate Elongation, per cent	320
Brittle Temperature, °F	-22
Exhaust Gas Composition (gm-mol/100 gm)	
Al_2O_3	0.390
H	0.015
Cl	0.005
CO	0.895
CO_2	0.009
H_2	1.432
H_2O	0.074
HCl	0.631
N_2	0.255
AlCl	0.002

The first batch of Arcite 427B propellant yielded unacceptably low burning rates in early heavywall motor firings. Two corrective measures were initially considered: (1) increasing chamber pressure through a reduction in nozzle throat area; (2) tailoring the basic Arcite 427B formulation to achieve a higher matrix burning rate at the motor's design operating pressure. The first solution was rejected because of a requirement to maintain a minimum motor case safety factor of 2.0. Copper chromite, a common burning rate accelerator, was thus added to the propellant composition.

Two variations of the modified propellant were formulated and tested. The first, designated Arcite 486, contained a 0.06 per cent by weight additive of copper chromite; the second, Arcite 486A, contained 0.05 per cent copper chromite. Weighted average oxidizer particle sizes ($\overline{D}_w$) also differed: 53 microns in Arcite 486 and 120 microns in Arcite 486A. Motor burning rates were approximately 25 per cent high with Arcite 486 and 10 per cent low with Arcite 486A. In addition, specific impulse values were 2 to 6 per cent lower than with the original Arcite 427B. These results indicated that the copper chromite accelerator was introducing appreciable variations in the ballistic properties of the basic formulation.

A second batch of Arcite 427B was then formulated with a reduced $\overline{D}_w$ of 53 microns. This batch afforded specification motor performance in all remaining heavywall and flightweight motor firings. It was concluded that Arcite 427B was an acceptable propellant for the MARC 36A1 motor, but that tight control of oxidizer $\overline{D}_w$ would be necessary. Strand burning rate curves for the successful batch, Number 2808, are shown in Figure 3.

2.2.2 Grain Configuration

In its final design, the Arcite 427B propellant grain is extruded into the internal burning, key-hole configuration shown in Figure 4. The originally proposed design, however, was a centrally perforated, slotted-tube configuration (Figure 5). The latter design offers more flexibility in adjusting the burning surface to obtain the desired pressure-time response. The progressive-burning cylindrical perforation counteracts the regressive

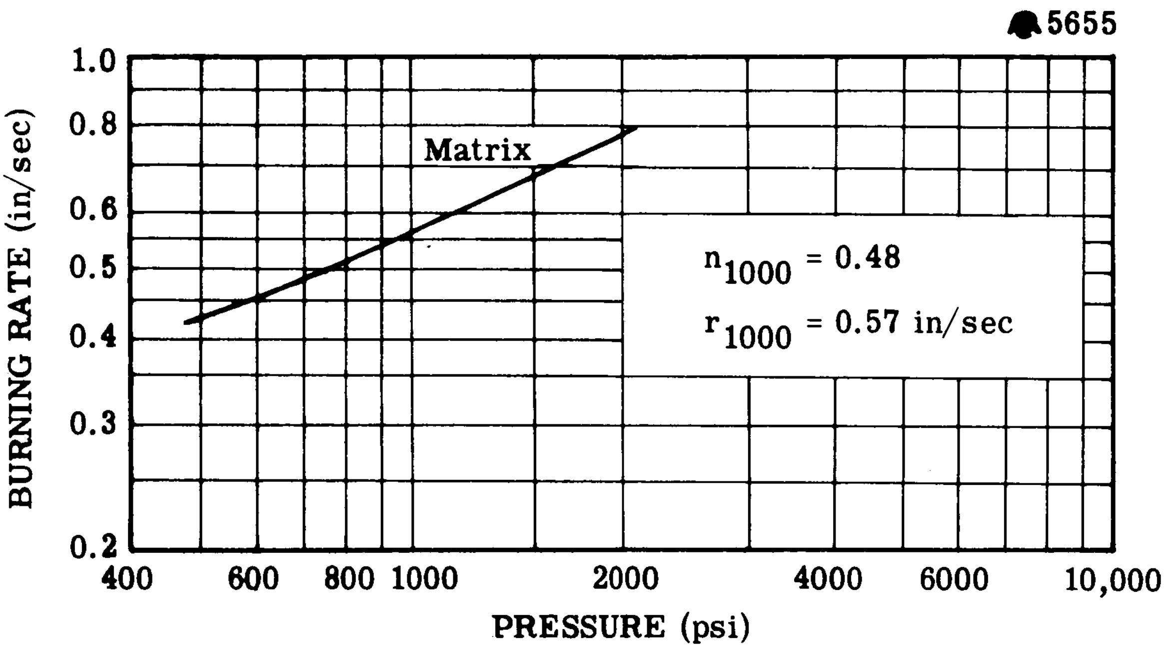

Figure 3. Strand Burning Rate Data Arcite 427B, Batch 2808.

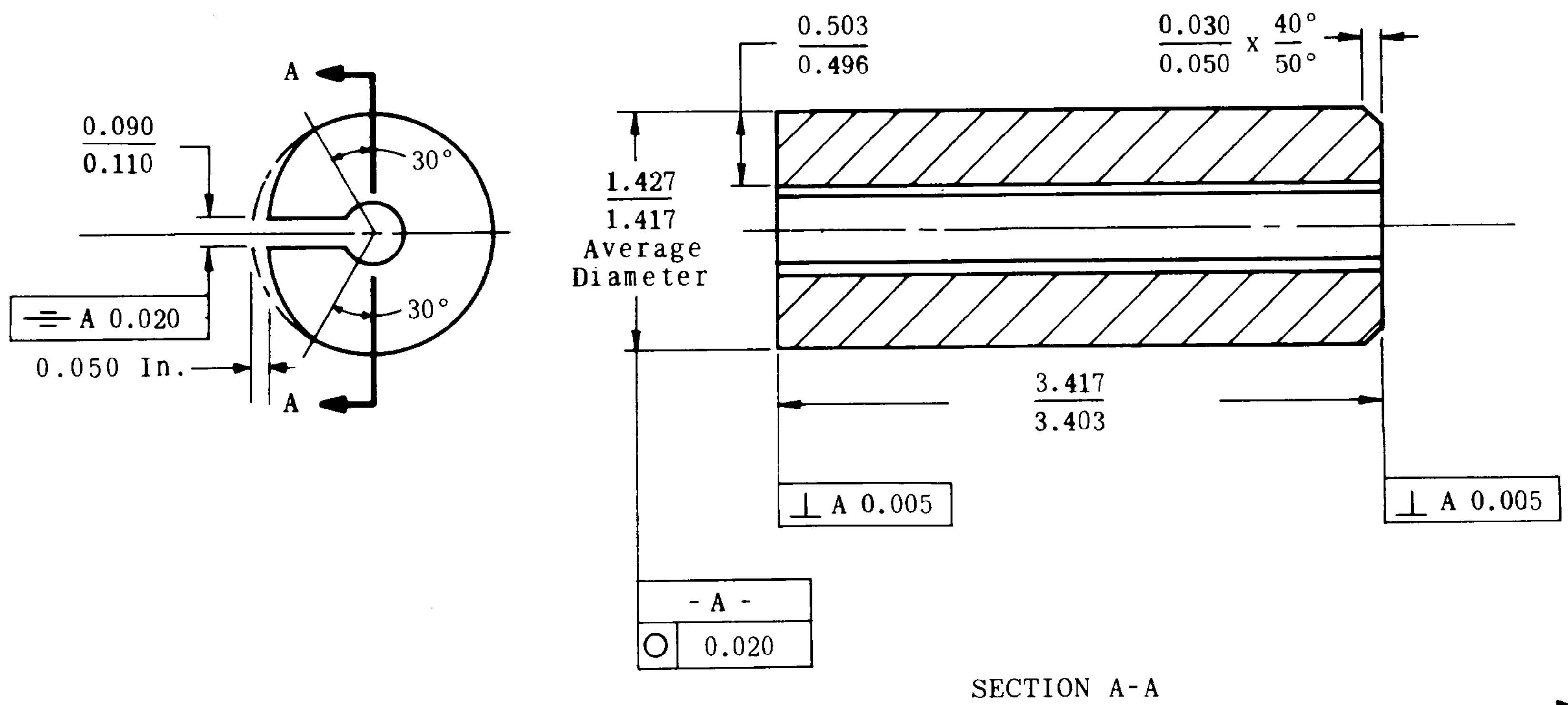

Figure 4. Key-Hole Propellant Grain Configuration.

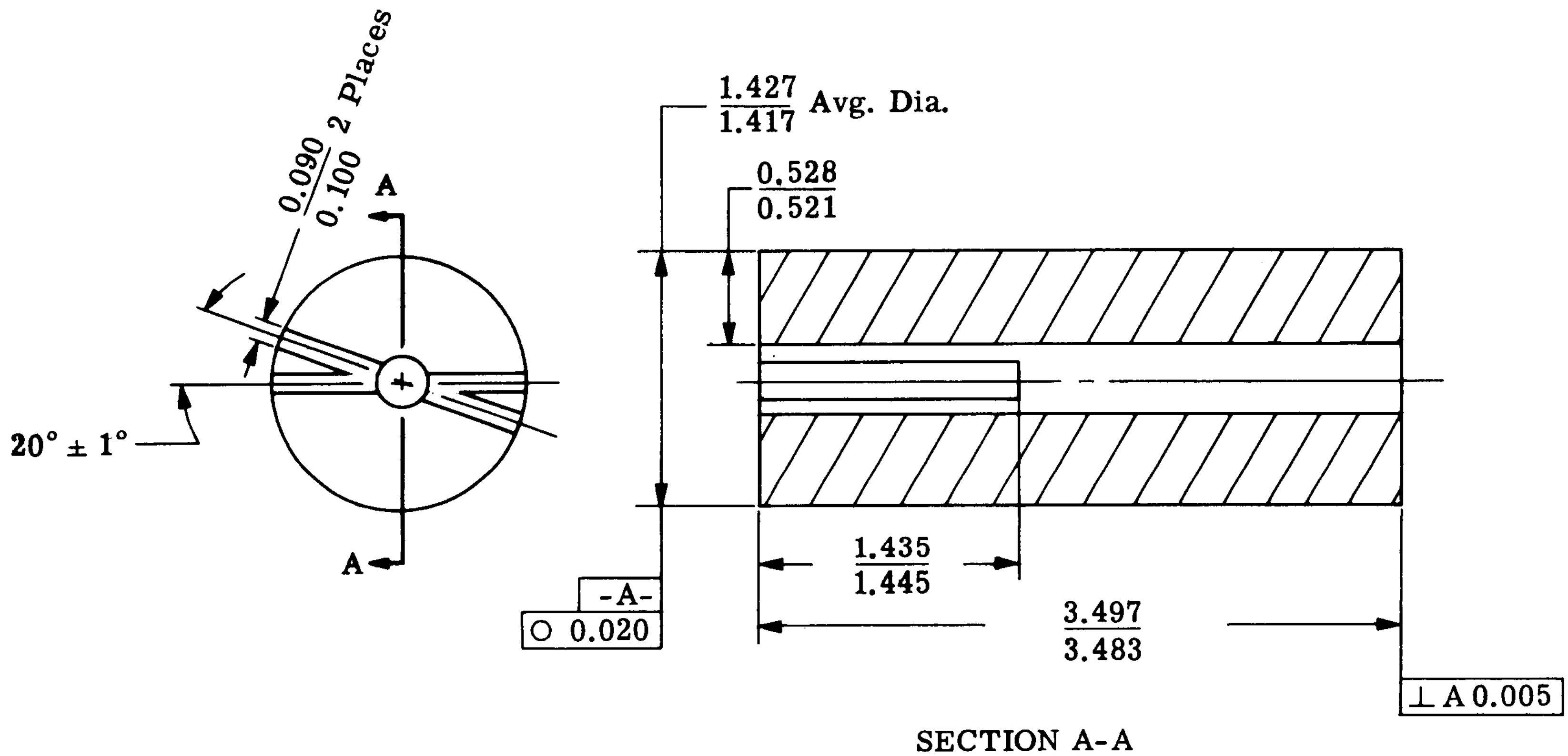

Figure 5. Proposed Slotted-Tube Grain Configuration.

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burning of the slots; thus, the surface area profile can be easily varied by altering the depths of the perforation.

The slotted-tube grain, however, proved to have two significant drawbacks: (1) it was not extrudable and had to be cast; (2) slotting the grain was difficult because of the thin strip of propellant between the slots. Several grain designs were considered after rejection of the slotted-tube configuration. The low propellant sliver required to meet the 0.200-second maximum tailoff time eliminated most candidates. Only grain designs with both a cylindrical center perforation and a slot were found capable of meeting all ballistic requirements. The key-hole grain was thus selected and developed. This grain is easily extruded to its final configuration, requiring only cutting to length and inhibiting before motor assembly.

2.3 INHIBITING SYSTEM

2.3.1 General Description

The propellant grain is fully inhibited on its outside circumference and aft end, and partially inhibited on its forward end. A thermal barrier over the keyway slot in the grain protects the motor case from direct exposure to high-temperature combustion products. Figure 6 depicts the inhibited key-hole grain.

Components and materials in the final inhibiting system are as follows:

a. A cotton stockinette circumferential inhibitor impregnated with titanium-dioxide-filled, EP-12 epoxy-polyamide resin

   (1) Stockinette - Number 2 White Cotton Surgitube manufactured by the Surgitube Product Corporation, Bronx, New York.

   (2) EP-12 Resin - Composed of 60 per cent Genepoxy 196 and 40 per cent Versamid 140, both products of the General Mills Chemical Division.

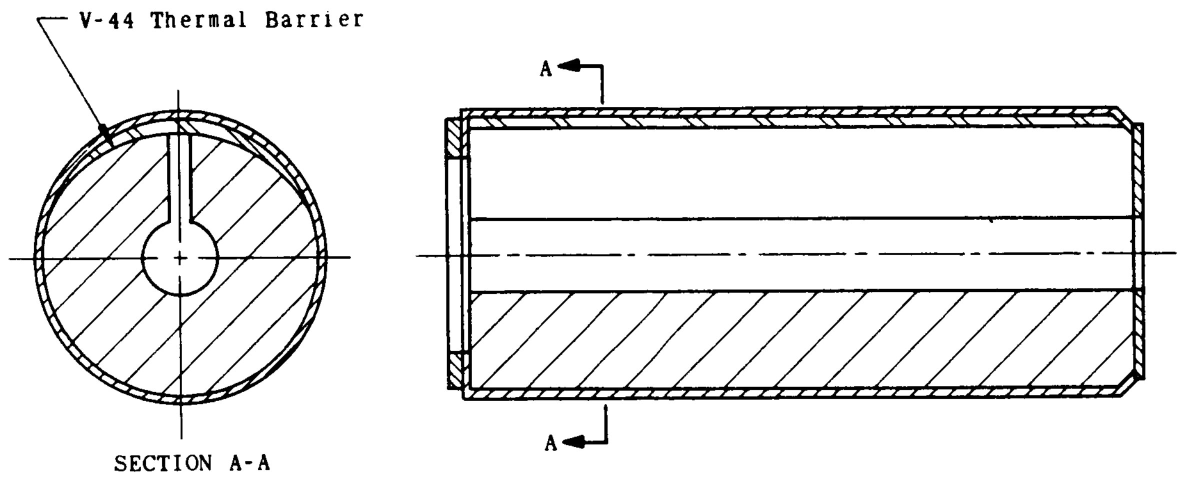

Figure 6. Inhibited Key-Hole Grain With Thermal Barrier.

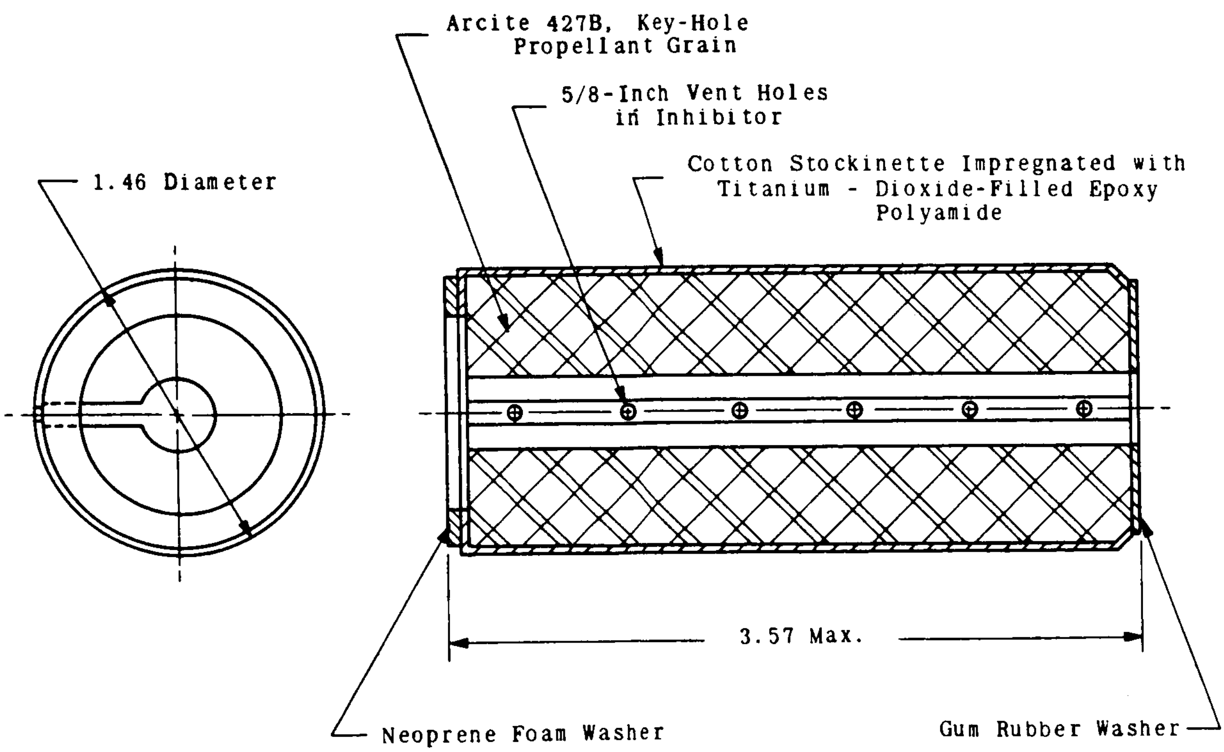

Figure 7. Inhibited Key-Hole Grain Before Addition of Thermal Barrier.

(3) Titanium Dioxide Filler - Manufactured by E. I. duPont de Nemours and Co., and certified to Federal Specification TTP-442, Type III, Grade A.

b. An aft-end washer press-molded from gum rubber stock manufactured by the Schenuit Rubber Company and certified to MIL-STD-417, Type R, Class RN or RS 510-4.

c. A head-end washer composed of neoprene foam rubber manufactured by Rubatex Corporation, Bedford, Virginia, and certified to MIL-C-3133, Grade SCE3.

d. A thermal barrier of Gen-Gard V-44, a product of the General Tire and Rubber Company composed of a butadiene-acrylonitrile (Buna-N) rubber containing hydrated silica, asbestos fibers, reinforcing resin, a plasticizer, and an antioxidant (plus other proprietary processing and vulcanizing agents).

2.3.2 Circumferential Inhibitor

The original circumferential inhibitor consisted of a nylon sleeve impregnated with titanium-dioxide-filled, epoxy-polyamide resin. Application of this sleeve, however, proved quite time consuming. A similarly impregnated, preformed cotton stockinette and an epoxy-bonded Latex rubber sleeve were thus tested as candidate replacements. Although easier to process, the Latex inhibitor proved to be of marginal structural integrity. In three of seven heavywall motor firings, pieces of Latex were ejected through the nozzle. Subsequent heavywall and flightweight motors therefore incorporated the cotton stockinette inhibitor.

Nominal thickness of the impregnated cotton sleeve is 0.015 inch. The titanium dioxide comprises a 5 per cent by weight additive to the EP-12 resin. As a white solid, it both enhances the high-temperature properties of the inhibitor and reflects radiant heat.

Early in development, the cotton stockinette was saturated with EP-54 (60/40, Versamid/Genepoxy) and then coated (e.g., not impregnated) with titanium dioxide powder. In four heavywall motor firings with this system, one pressure-time trace indicated that inhibitor particles had been expelled through the nozzle near web burnout. The epoxy-polyamide formulation was then changed from EP-54 to EP-12 to afford greater strength and improved high-temperature properties. Asbestos fibers were initially used as the filler material to add mass and provide improved mechanical properties at high temperatures. Firing results, however, again showed evidence of inhibitor discharges near end of tailoff. The final circumferential inhibitor was then developed and successfully tested. The asbestos staples were replaced with titanium dioxide powder, applied not as a surface coating, but premixed with the EP-12 resin.

2.3.3 Addition of Thermal Barrier

For heavywall motor firings, vent holes were drilled through the impregnated cotton stockinette along the length of the grain adjacent to the keyway slot. This system permitted exhaust gases to pass rapidly from the internal to the external port and, thus, to equalize chamber pressure throughout the motor. When this design (Figure 7) was used in the first two flightweight motor firings, both H-11 steel motor cases overheated in line with the keyway slot and ruptured. (See Figure 8.) Failure analysis indicated that the inhibitor allowed the case to be subjected to flame temperature in excess of 5000°F. It was also concluded that this would have occurred even without the vent holes, since the cotton over the slot burns away shortly after ignition. The maximum wall thickness of the H-11 steel is only 0.030 inch. Under direct flame exposure, it cannot absorb or dissipate sufficient heat to maintain the strength required to withstand 950 psia for 1 second.

A circumferential inhibitor was thus developed which would confine combustion completely within its perimeter. Ballistic calculations showed that impulse requirements could be met if a thin, 120-degree crescent of propellant was removed from the outside grain surface, as depicted below:

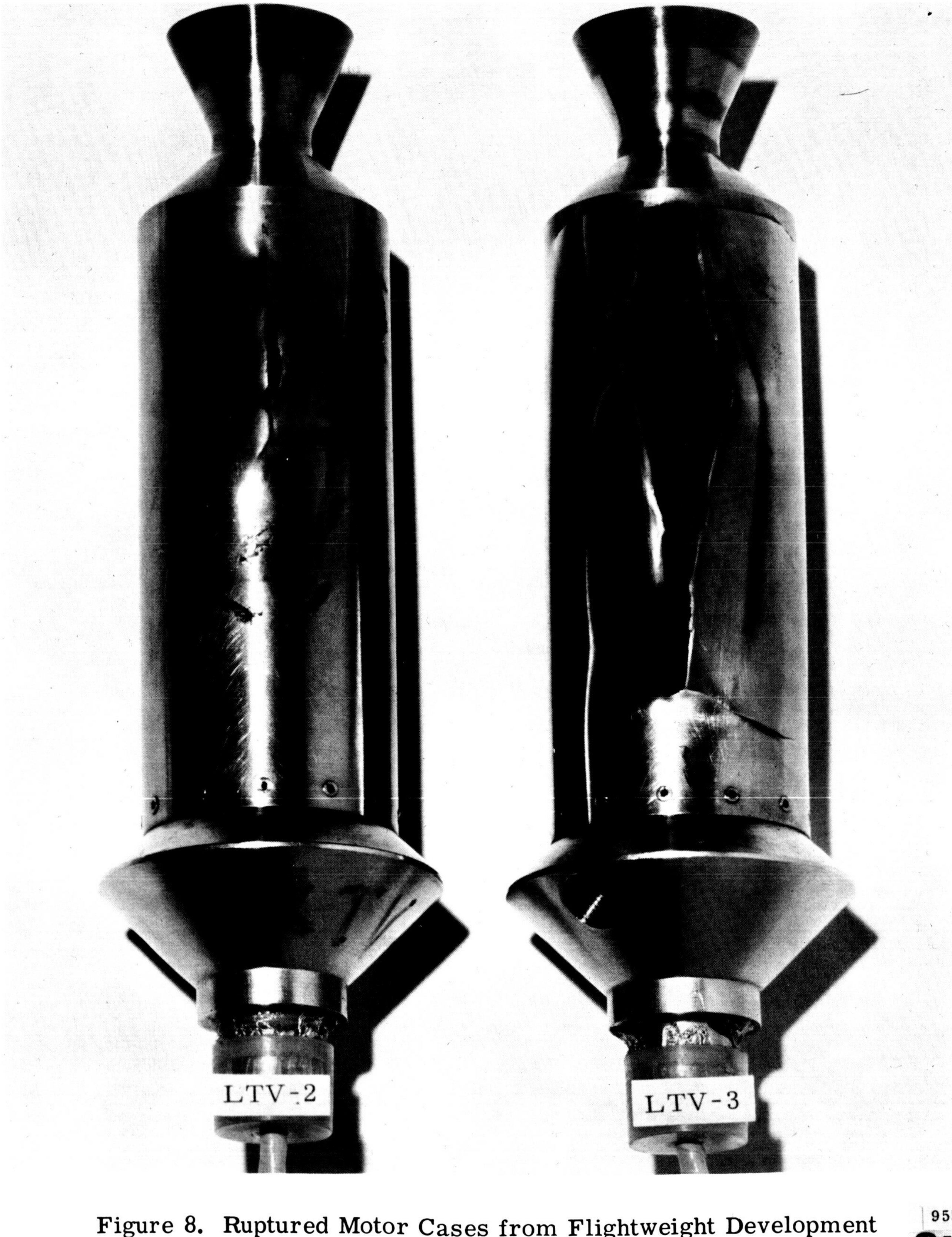

Figure 8. Ruptured Motor Cases from Flightweight Development Firings LTV-2 and LTV-3.

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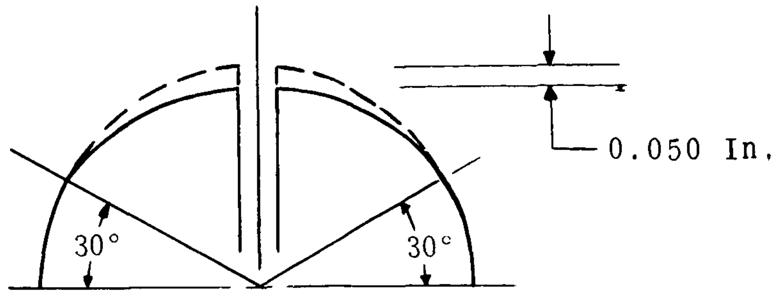

The propellant in this area was then replaced with a thermal barrier, bonded between the propellant and the impregnated cotton sleeve.

Sample strips of two candidate materials -- Gen-Gard V-44 and Dow Corning 325 -- were molded into the required crescent shape. Molding conditions for the Gen-Gard V-44 were 30 minutes at 900 psi and 315°F; for the Dow Corning 325, 5 minutes at 900 psi and 300°F. The V-44 strips were bonded to grains with the same EP-12 epoxy-polyamide resin used to impregnate the cotton stockinette inhibitor. A special Dow Corning bonding agent -- Number 92-018 Aerospace Adhesive, however, was required for the Silicone 325.

Both barrier materials were then evaluated in heavywall and flightweight motor firings. Thrust-time records from motors with Silicone 325 barriers were slightly erratic. Further, the V-44 barrier proved easier to install and less costly. Flightweight case skin temperatures were significantly reduced by both materials. Thermocouple data from motors with and without thermal barriers are compared in Table II. On the basis of these results, the Gen-Gard V-44 was selected for incorporation into the final motor design.

2.3.4 <u>End Washers</u>

Both end washers are bonded to the propellant surface with EP-12 epoxy-polyamide resin. (See Figure 9.) The neoprene washer at the head end serves mainly as a spacer to trap the grain in the motor. Initially, a nylon scrim disc permeated with EP-54 resin was used at the aft end. To avoid the possibility of fragmentation, this rigid disc was later replaced with a more flexible natural rubber.

Table II. Comparison of Motor Skin Temperatures With and Without Thermal Barrier.

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Motor Number	Motor Temperature (°F)	Time	Case Temperature (°F)		
			T/C 1	T/C 2	T/C 3
		WITHOUT THERMAL BARRIER			
LTV-2	77	Ignition	70	70	70
		0.423 sec*	1005	147	73
LTV-3	77	Ignition	73	73	73
		0.568 sec*	288	258	73
		WITH THERMAL BARRIER			
X-1	130	Ignition	106	102	102
		Web Burnout	106	109	157**
		13.0 sec	177	167	546**
X-5	130	Ignition	92	95	90
		Web Burnout	95	95	123**
		16.0 sec	130	126	598**
X-6	20	Ignition	47	54	47
		Web Burnout	153	54	54
		8.0 sec	200	64	303

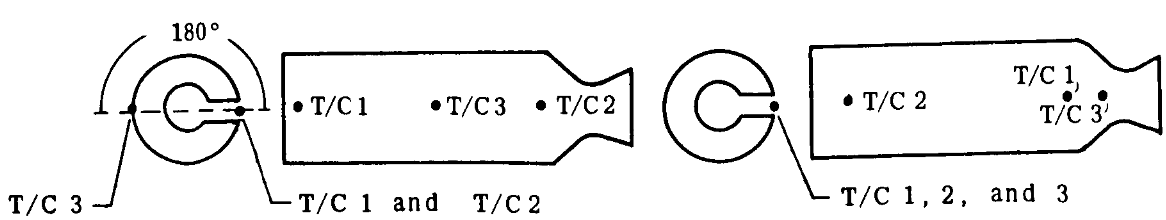
* Time of Failure

** Affected by nozzle burn-through

Thermocouple Locations

Motors LTV-2, 3

Motors X-1, 5, 6



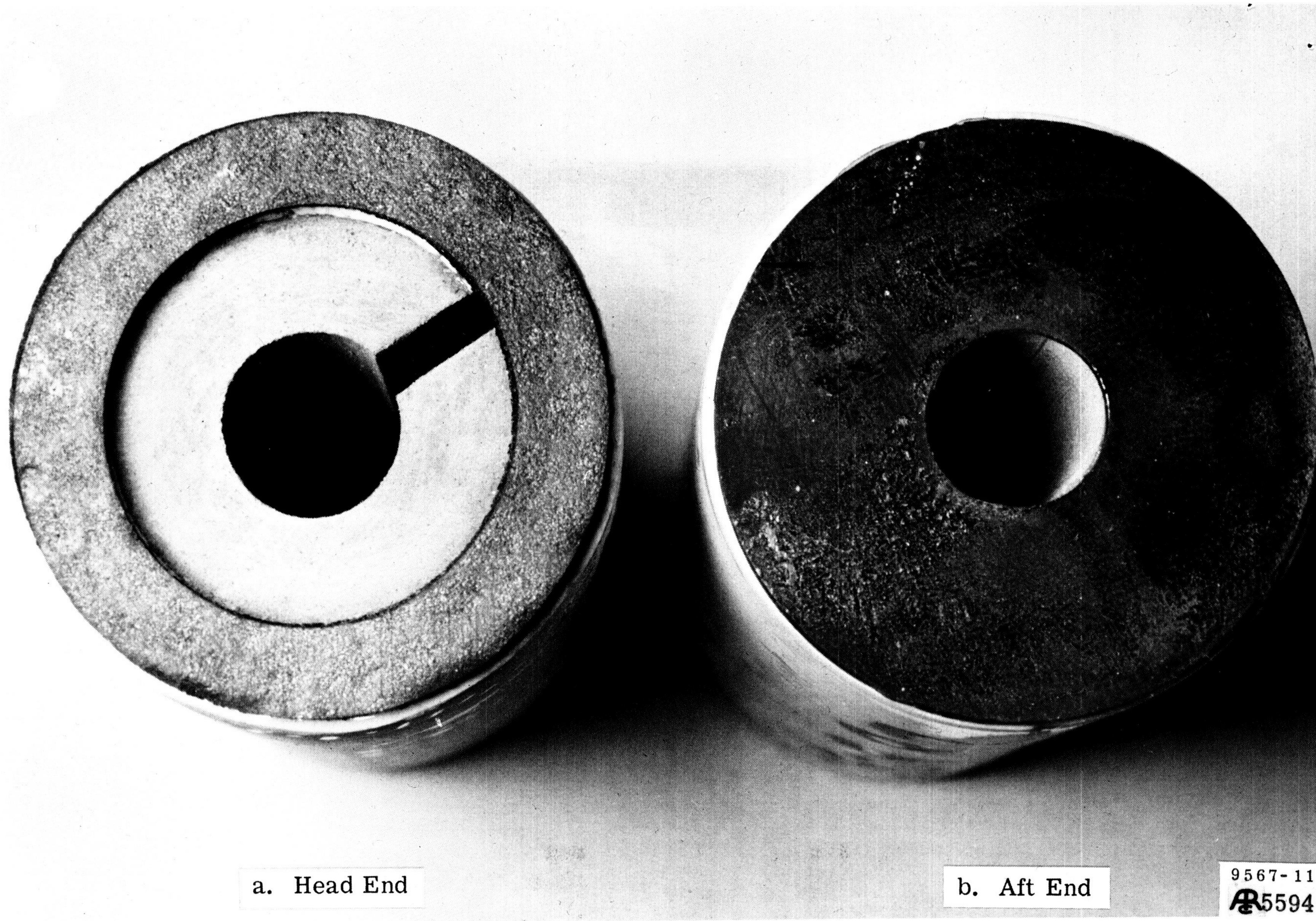


Figure 9. End Views of Inhibited Key-Hole Grain.

2.4 HARDWARE

The motor case is fabricated from high-strength H-11 steel, with D6A steel permitted as an alternate material. Required ultimate tensile strength after heat treat is between 220,000 and 240,000 psi. The Model 501 igniter, integrated into the motor's head closure, is held in the motor by twelve spring pins. Nozzle components include a molded ATJ graphite throat insert and a silicone rubber nozzle closure which seats within the insert. During development, two flightweight hardware assemblies were subjected to hydrostatic pressure tests. The test assembly consisted of simulated Model 501 igniter bodies, with pressure taps, pinned into H-11 steel motor cases. Each case was pressurized at 100 psi/sec until failure occurred. In both tests, the steel spring pins sheared at a pressure greater than 4000 psi. Failure pressure in the first test was 4300 psi; in the second, 4100 psi. These values are well in excess of the 1150-psi maximum operating pressure.

2.5 IGNITER

The Model 501 igniter contains two Flare-Northern Division (FND) Model 908B electric squibs, wired in parallel, and a main charge of 0.478 gram of FND 2M boron-potassium-nitrate pellets. Glass-to-metal seals secure the leadwire pins within the igniter body. Either squib functions when a direct current of at least 1.2 amperes is applied through its 2.5-mil nichrome bridgewire.

A main igniter charge of 0.75 gram of 2M pellets was used throughout the heavywall development program. Ignition thrusts in the initial flightweight motor firings, however, exceeded the specification limit of 70 pounds at 77°F. Subsequent firings indicated that a reduction from 0.75 to 0.478 gram would afford lower ignition thrusts without detrimentally affecting propellant ignition.

3. TEST PROGRAM

3.1 STATIC FIRINGS

3.1.1 Test Objectives

Thirty-five heavywall motors and 27 flightweight MARC 36A1 motors were static-fired during the program. All motors were fired in a vacuum chamber test facility after having been conditioned to a temperature of 20°F, 77°F (74°F for heavywall motors), or 130°F. Figures 10 and 11 show a typical flightweight motor being readied for firing. Ambient pressure in the test chamber was reduced to less than 0.04 psia during test.

Test objectives were as follows:

a. Thirty-two heavywall motors, LTVD-1 through -32, were fired to develop a propellant grain, nozzle throat area, expansion ratio, and igniter charge which would result in a flightweight motor capable of performing within specification limits.

b. Three heavywall motors, LTVD-33, -34, and -35, were fired to evaluate effects of candidate thermal barriers and reduced igniter charge at 130°F.

c. Three flightweight motors, X-1, -5, and -6, were fired to evaluate effects of candidate thermal barriers and reduced igniter charge at 20°F and 130°F.

d. Nine flightweight motors, LTV-1 through -9, were fired in fulfillment of contractual requirements for a nine-round flightweight development test series.

e. Fifteen flightweight motors, PFRT-1 through PFRT-15, were fired to complete program requirements for Preflight Rating Tests (PFRT).

Ballistic criteria, as set forth in LTV Specification 304-411, were as follows:

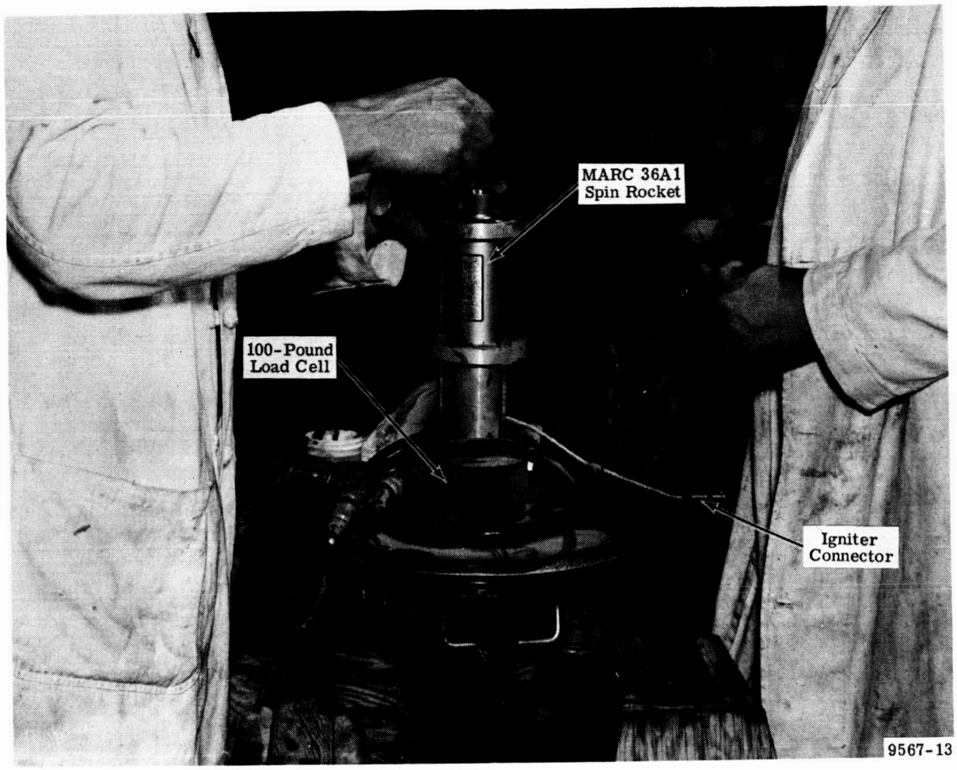


Figure 10. Installation of Rocket Motor on Thrust Stand.

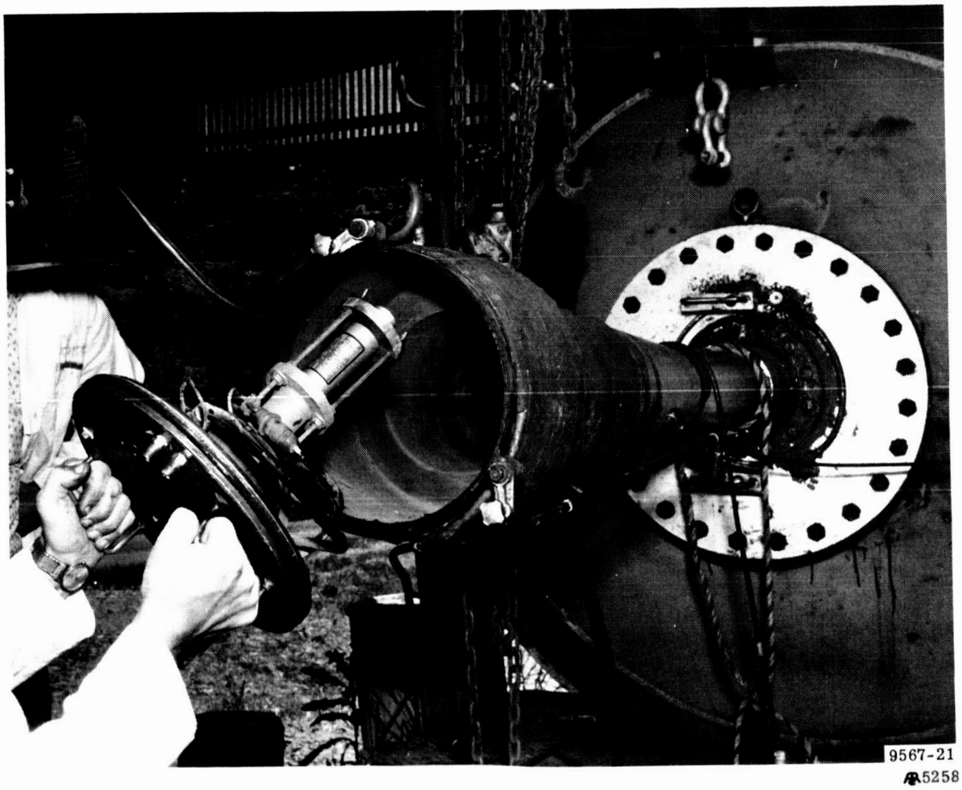


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Figure 11. Installation of Instrumented Motor into Diffuser Tube.

a. A minimum total impulse of 75 pound-seconds over the temperature range from 20°F to 130°F.

b. A nominal web burning time of 1.0 second at 77°F.

c. A maximum ignition thrust peak of 70 pounds at 77°F.

d. A maximum progressivity ratio (F_{max}/F_{ign}) of 1.3 at 77°F.

e. A maximum tailoff time of 0.200 second at 77°F.

3.1.2 Test Results

Ballistic data summaries are presented for the heavywall motors, the three X-Series flightweight motors, the flightweight development motors, and the PFRT motors in Tables III, IV, V, and VI, respectively. Case skin temperatures from the flightweight development firings and the PFRT firings are presented in Tables VII and VIII. Figure 12 depicts typical thrust-time responses from a flightweight motor at 20°F, 77°F, and 130°F.

Design changes effected as a result of the first 32 heavywall motor firings are discussed in Section 2.0. At the end of this series, all performance requirements were being met except for progressivity ratios greater than the allowable maximum of 1.3 at 77°F. After reviewing these results, Ling-Temco-Vought authorized the initiation of flightweight development testing.

The first two flightweight development motors, LTV-2 and LTV-3, were fired on May 13, 1965, at 77°F. Both motors malfunctioned in a similar fashion. Motor LTV-2 burned for 0.419 second, at which time the motor case ruptured; in LTV-3, the time of failure was 0.572 second. Post-test analysis showed the cause of failure in both motors to be overheating of the case adjacent to the keyway slot in the grain. The solution to this problem was the adoption of a V-44 thermal barrier over the slot as discussed in Section 2.3.3. Excessive ignition peaks of 78.50 and 81.07 pounds were also obtained in the two firings.

To reduce the ignition thrust in flightweight motors, the amount of boron-potassium-nitrate 2M pellets was decreased from 0.75 to 0.478 gram.

Table III. Ballistic Data Summary for MARC 36A1 Heavywall Tests.

AR5634

Motor Number[f]	Grain Number[l i]	Date 2/65	W_p (lb)	Web (in)	A_e (sq in)	Throat Area Before (sq in)	Throat Area After (sq in)	t_d (sec)	t_i (sec)	t_b (sec)	$t_{tail\text{-}off}$ (sec)	$\bar{r}$ (in/sec)
						20°F MOTOR TEMPERATURE						
LTVD-1	2631-30B	15	0.3080	0.500	0.9976	0.0415	0.0404	0.016	0.020	1.214	---	0.4119
LTVD-2	2631-30A	15	0.3042	0.496	0.9976	0.0404	0.0406	0.012	0.014	1.161	---	0.4272
LTVD-5[a]	2631-32B	23	0.3071	0.527	0.9348	0.0414	0.0382	0.021	0.034	---	---	---
LTVD-7	2631-33A	26	0.3111	0.526	0.9366	0 0350	0.0350	0.033	0.050	1.271	0.176	0.4138
LTVD-31	2808-R2-31B	5-11	0.3039	0.4985	0.9590	0.0454	0.0420	0.008	0.016	1.088	0.114	0.4582
						74°F MOTOR TEMPERATURE						
LTVD-3[b]	2631-30C	16	0.3100	0.499	0.9976	0.0415	0.0414	0.021	0.040	1.159	---	0.4305
LTVD-4	2631-32C	22	0.3069	0.522	0.9348	0.0415	0.0414	0.022	0.032	1.338	0.146	0.3901
LTVD-6[a]	2631-33C	26	0.3084	0.526	0.9642	0.0345	0.0324	0.036	0.047	---	---	---
LTVD-9	2631-35B	5	0.3086	0.5255	0.9366	0.0320	0.0317	0.005	0.016	1.190	0.095	0.4416
LTVD-10[g]	2631-35A	5	0.3115	0.5255	0.9590	0.0313	0.0311	0.008	0.028	1.166	--	0.4507
LTVD-13[h]	394T-2E	23	0.3113	0.519	0.9366	0.0473	0.0473	0.010	0.032	0.950	0.101	0.3463
LTVD-14[h]	394T-2A	23	0.3093	0.498	0.9590	0.0468	0.0464	0.005	0.012	0.866	0.115	0.5751
LTVD-17	394T-1B	26	0.3093	0.501	0.9366	0.0598	0.0568	0.007	0.055	0.988	0.061	0.5071
LTVD-18	394T-1C	31	0.3109	0.5035	0.9590	0.0560	0.0556	0.008	0.030	0.982	0.066	0.5127
LTVD-19	399T-1C	9	0.306	0.503	0.9590	0.0454	0.0469	0.008	0.021	1.158	0.131	0.4344
LTVD-20	399T-1B	13	0.306	0.498	0.9643	0.0398	0.0432	0.009	0.027	1.148	0.102	0.4338
LTVD-21[j]	404T-2A	22	0.305	0.501	0.9366	0.0552	0.0524	0.007	0.020	0.800	0.105	0.6263
LTVD-22	404T-2B	22	0.307	0.502	0.9642	0.0554	0.0523	0.005	0.012	0.845	0.113	0.5941
LTVD-23[k]	2808-45A	26	0.308	0.498	0.9366	0.0368	0.0353	0.009	0.017	0.989	0.171	0.5035
LTVD-24	2808-47C	26	0.309	0.497	0.9590	0.0370	0.0362	0.007	0.017	1.009	0.110	0.4926
LTVD-25	2808-47A	26	0.309	0.500	0.9591	0.0426	0.0401	0.006	0.013	1.032	0.076	0.4845
LTVD-26	2808-47D	27	0.310	0.501	0.9643	0.0447	0.0419	0.006	0.013	1.065	0.071	0.4704
LTVD-27	2808-R2-33B	5-9	0.3038	0.497	0.9368	0.0452	0.0414	0.007	0.026	1.044	0.097	0.4761
LTVD-28	2808-R2-33C	5-9	0.3038	0.498	0.9642	0.0452	0.0426	0.011	0.017	1.020	0.089	0.4882
LTVD-29	2808-R2-33D	5-11	0.3038	0.496	0.9590	0.0452	0.0419	0.008	0.018	1.037	0.130	0.4783
LTVD-30	2808-R2-34A	5-11	0.3038	0.497	0.9368	0.0451	0.0419	0.008	0.013	0.977	0.093	0.5087
						130°F MOTOR TEMPERATURE						
LTVD-8	2631-33B	26	0.3064	0.523	0.9555	0.0350	0.0337	0.068	0.073	1.173	0.126	0.4459
LTVD-11	2631-33D	5	0.3110	0.5285	0.9642	0.0316	0.0314	0.013	0.029	1.154	0.095	0.4580
LTVD-12	2631-35D	5	0.3113	0.527	0.9590	0.0314	0.0319	0.019	0.006	1.115	--	0.4726
LTVD-15	394T-2B	23	0.3089	0.5225	0.9642	0.0470	0.0468	0.005	0.012	0.901	0.060	0.5799
LTVD-16[h]	394T-2D	23	0.3075	0.498	0.9366	0.0471	0.0464	0.008	0.011	0.849	0.081	0.586
LTVD-32	2808-R2-32A	5-11	0.3039	0.498	0.9642	0.0452	0.0426	0.006	0.016	0.988	0.118	0.5040
LTVD-33	2808-R2-35C	5-16	0.2919	0.4945	0.9642	0.0449	0.0410	0.040	0.044	0.993	0.101	0.4980
LTVD-34	2808-R2-37C	5-16	0.2932	0.4955	0.9590	0.0449	0.0412	0.035	0.038	1.000	0.094	0.4955
LTVD-35	2808-R2-35D	5-16	0.2926	0.4945	0.9314	0.0449	0.0439	0.043	0.051	1.007	0.075	0.4911

Table III. Ballistic Data Summary for MARC 36A1 Heavywall Tests. (Cont'd)

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Motor Number [f]	P_{max} (psia)	P_b (psia)	F_{ign} (lb)	F_{max} (lb)	F_b (lb)	Progressivity Ratio	I_{0-0} (lb-sec)	$\int P_{dt}(0-0)$ (psia-sec)	I_{sp} (lb-sec/lb)	C_D (lb/lb-sec)	c^{*} [a] (ft/sec)	$\bar{P}_{tunnel}$ (psia)
						20° F MOTOR TEMPERATURE						
LTVD-1	1155	915.7	81.63	80.04	63.60	0.981	79.28	1141	257.4	0.00661	4872	0.0358
LTVD-2	1155	942.9	95.20	80.21	66.22	0.843	79.17	1127	260.3	0.00668	4825	0.0339
LTVD-5 [a]	1335	---	54.23	90.11	--	1.662	---	---	---	---	---	0.0380
LTVD-7	1200	1050	58.63	69.74	60.88	1.189	79.31	1374	254.9	0.00650	4970	0.0353
LTVD-31	1016	935.3	55.73	75.27	69.57	1.351	77.16	1037	253.9	0.00671	4798	0.0208
						74° F MOTOR TEMPERATURE						
LTVD-3 [b]	1223	914.2	69.49	82.35	63.35	1.185	78.38	1123	252.8	0.00669	4834	0.0259
LTVD-4	905.9	837.1	60.41	60.41	57.03	1.000	78.20	1154	254.8	0.00643	5018	0.0451
LTVD-6 [a]	1914	---	61.59	108.4	---	1.760	---	---	---	0.00669	4911	0.0327
LTVD-9	1318	1215	60.29	69.59	65.66	1.154	79.51	1475	257.6	0.006569	4896	0.0297
LTVD-10 [g]	1337	1225	69.92	63.91	60.45	0.914	72.11	1462	231.5	0.006829	4709	0.0357
LTVD-13 [h]	1204	1097	78.89	91.26	82.13	1.157	79.61	1064	255.7	0.006185	5198	0.0264
LTVD-14 [h]	1268	1179	75.32	94.44	87.00	1.254	78.30	1063	253.2	0.006243	5150	0.0242
LTVD-17	1073	877.5	61.51	90.60	78.09	1.473	78.24	886.2	253.0	0.005896	5371	0.0257
LTVD-18	978.7	877.1	64.47	87.54	78.88	1.358	78.75	874.2	253.3	0.006373	5048	0.0183
LTVD-19	851.3	804.4	56.57	68.00	63.04	1.202	73.92	944.3	241.2	0.00702	4578	0.0905
LTVD-20	981.6	906.7	57.43	68.49	64.07	1.193	74.67	1057	244.0	0.00699	4612	0.0186
LTVD-21	1135	1046	79.10	100.6	91.76	1.272	74.57	850.5	244.5	0.00669	4827	0.0192
LTVD-22	1151	999.2	79.01	104.8	89.72	1.326	76.80	859.5	250.2	0.00667	4846	0.0233
LTVD-23	1369	1325	74.59	84.39	78.63	1.131	78.85	1362	256.2	0.00646	5139	0.0188
LTVD-24	1312	1260	74.90	83.30	76.84	1.112	78.88	1294	255.3	0.00654	4931	0.0186
LTVD-25	1134	1078	70.99	79.91	75.22	1.126	78.55	1127	254.2	0.00663	4858	0.0220
LTVD-26	1056	989.2	63.59 [m]	79.09	72.92	1.244	78.65	1067	253.7	0.00672	4795	0.0238
LTVD-27 [c]	—	—	56.36	78.04	75.21	1.385	77.09	—	253.8	—	—	0.0205
LTVD-28	1069	990.2	61.82	80.40	73.71	1.301	76.82	1036	252.9	0.00671	4817	0.0223
LTVD-29	1075	986.1	56.25	78.60	73.02	1.397	77.35	1050	254.6	0.00665	4848	0.0186
LTVD-30	1075	1054	61.62	79.58	77.34	1.291	77.15	1053	253.9	0.00666	4849	0.0196
						130°F MOTOR TEMPERATURE						
LTVD-8	1888	1132	61.16	109.7	65.96	1.794	78.37	1347	255.8	0.00665	4849	0.0382
LTVD-11	1668	1259	61.90	89.68	68.10	1.449	79.97	1477	257.1	0.006684	4810	0.0306
LTVD-12	1381	1309	71.51	75.30	70.61	1.053	80.56	1496	258.8	0.006564	4898	0.0300
LTVD-15	1210	1122	88.26	92.01	86.37	1.042	79.60	1034	257.7	0.006369	5048	0.0239
LTVD-16 [h]	1430	1181	78.55	108.6	90.04	1.383	78.30	1027	254.6	0.006397	5026	0.0234
LTVD-32 [d]	1208	1102	62.96	83.95	76.91	1.333	77.62	—	255.4	0.00623	—	0.0221
LTVD-33 [e]	—	—	61.08	79.05	73.74	1.294	74.58	—	255.5	—	—	0.0107
LTVD-34 [e]	—	—	61.92	83.64	73.68	1.351	74.67	—	254.8	—	—	0.0223
LTVD-35 [e]	—	—	64.13	77.87	72.67	1.214	74.63	—	255.1	—	—	0.0204

a. Inhibitor and spacer discharge on tail-off.
b. Indication of spacer discharge at 0.877 sec from 1st indication.
c. Pressure data lost.
d. Pressure tap plugged at 1.036 seconds after t_0; $P_{dt}(0-0)$ unattainable.
e. Pressure data not valid; pressure returned to balance prior to 0 thrust.
f. Motors LTVD-9, -10, -11, -12, -13, and -15 contained slotted-tube grains; other motors contained key-hole grains.
g. Cap was left on diffuser tube; data may be erroneous.
h. Inhibitor fragments discharged through nozzle.
i. Batch Number 2631, Arcite 427B; Batch Number 394T, Arcite 486.
j. Inhibitor discharge at web burnout.
k. Inhibitor discharge near end of tail-off.
l. Batch 399T, Arcite 486A; Batch 404T, Arcite 486; Batch 2808, Arcite 427B.
m. Ignition surface area reduced by increasing size of head-end spacer.

Table IV.– Ballistic Data Summary for MARC 36A1 X-Series Flightweight Tests.

Motor Number	Grain Number	Date 1965	W_p (lb)	Web (in)	A_e (sq in)	Throat Area Before (sq in)	Throat Area After (sq in)	t_d (sec)	t_i (sec)	t_b (sec)	$t_{tail-off}$ (sec)	$\bar{r}$ (in/sec)	P_{max} (psia)
					20° F MOTOR TEMPERATURE								
X-6	2808-R2-35B	5-19	0.2930	0.495	0.9503	0.0454	0.0434	0.008	0.017	1.088	0.076	0.4550	1023
					130° F MOTOR TEMPERATURE								
X-1[b]	2808-R2-35A	5-17	0.2936	0.4955	0.9503	0.0475	0.0473	0.014	0.019	1.028	0.108	0.4820	1002
X-5[b]	2808-R2-37A	5-17	0.2917	0.4954	0.9503	0.0452	0.0439	0.008	0.018	1.018	0.071	0.4866	1063

Motor Number	P_b (psia)	F_{ign} (lb)	F_{max} (lb)	F_b (lb)	Progress-ivity Ratio	I_{0-0} (lb-sec)	$\int P_{dt}(0-0)$ (psia-sec)	$I_{sp}(0-0)$ (lb-sec/lb)	C_D (lb/lb-sec)	C* (ft/sec)	$\bar{P}_{tunnel}$ (psia)
					20° F MOTOR TEMPERATURE						
X-6	895.9	59.68	77.12	67.39	1.292	74.61	990.2	254.6	0.00666	4828	0.0102[a]
					130° F MOTOR TEMPERATURE						
X-1	915.8	68.73	79.10	72.40	1.151	75.83	959.7	258.3	0.00645	4985	0.0183
X-5	951.9	61.12	81.33	72.64	1.331	75.24	986.4	257.9	0.00663	4852	0.0164

a. Preignition value shown; unable to obtain average value.

b. Case burnthrough occurred aft of nozzle throat.

Table V. Ballistic Data Summary for MARC 36A1 Development Tests.

AR5282

Motor Number	Grain Number	Date (1965)	W_p (lb)	Web (in)	A_e (sq in)	Throat Area Before (sq in)	Throat Area After (sq in)	t_d (sec)	t_i (sec)	t_b (sec)	$t_{tail-off}$ (sec)	$\bar{r}$ (in/sec)	P_{max} (psia)
						20°F MOTOR TEMPERATURE							
LTV-4	2808-R2-95C	5/30	0.2956	0.497	0.9503	0.0452	0.0430	0.007	0.011	1.075	0.088	0.4623	1069
LTV-5[a]	2808-R2-23C	5/30	0.2956	0.497	0.9503	0.0452	0.0430	--	--	--	--	--	--
LTV-6	2808-R2-94D	5/30	0.2956	0.497	0.9503	0.0452	0.0430	0.005	0.012	1.080	0.078	0.4602	1108
						77°F MOTOR TEMPERATURE							
LTV-1	2808-R2-23A	5/30	0.2978	0.497	0.9503	0.0452	0.0435	0.008	0.011	1.052	0.095	0.4724	1082
LTV-2[b]	2808-R2-34B	5/13	0.3034	0.496	0.9503	0.0456	--	0.006	0.010	--	--	--	--
LTV-3[c]	2808-R2-28C	5/13	0.3029	0.497	0.9503	0.0456	--	0.007	0.010	--	--	--	--
						130°F MOTOR TEMPERATURE							
LTV-7	2808-R2-94C	5/30	0.2963	0.497	0.9503	0.0452	0.0450	0.010	0.017	1.028	0.096	0.4835	1108
LTV-8	2808-R2-86D	5/30	0.2954	0.496	0.9503	0.0452	0.0449	0.004	0.010	1.034	0.094	0.4797	1070
LTV-9	2808-R2-23B	5/30	0.2952	0.497	0.9503	0.0452	0.0434	0.005	0.013	1.032	0.081	0.4816	1129

Motor Number	P_b (psia)	F_{ign} (lb)	F_{max} (lb)	F_b (lb)	Progressivity Ratio	I_{0-0} (lb-sec)	$\int P_{dt}$ (0-0) (psia-sec)	I_{sp} (0-0) (lb-sec/lb)	C_D (lb/lb-sec)	C* (ft/sec)	$\bar{P}_{tunnel}$ (psia)
					20°F MOTOR TEMPERATURE						
LTV-4	919.5	63.87	80.29	69.38	1.257	75.78	1004	256.4	0.00668	4819	0.0189
LTV-5[a]	--	--	--	--	--	--	--	--	--	--	--
LTV-6	957.4	61.41	76.84	69.10	1.251	75.90	1054	256.8	0.00636	5059	0.0165
					77°F MOTOR TEMPERATURE						
LTV-1	945.5	67.60	81.19	71.83	1.201	76.79	1010	257.9	0.00664	4845	0.0184
LTV-2[b]	--	78.50	--	--	--	--	--	--	--	--	--
LTV-3[c]	--	81.07	--	--	--	--	--	--	--	--	--
					130°F MOTOR TEMPERATURE						
LTV-7	995.5	67.94	80.27	73.06	1.181	76.50	1046	258.2	0.00628	5122	0.0162
LTV-8	983.6	67.54	78.68	72.60	1.165	76.30	1038	258.3	0.00632	5088	0.0167
LTV-9	972.9	64.59	81.14	72.64	1.256	76.18	1023	257.8	0.00651	4939	0.0184

a. Igniter fired but grain failed to ignite, (no 2M pellets in igniter).

b. Motor case ruptured and burning terminated at 0.419 second, (no V-44 thermal barrier).

c. Motor case ruptured and burning terminated at 0.572 second, (no V-44 thermal barrier).

Table VI. Ballistic Data Summary for MARC 36A1 Preflight Rating Tests.

Motor Number	Grain Number	Date (1965)	W_p (lb)	Web (in)	A_e (sq in)	Throat Area Before (sq in)	Throat Area After (sq in)	t_d (sec)	t_i (sec)	t_b (sec)	$t_{tail\text{-}off}$ (sec)	$\bar{r}$ (in/sec)	F_{ign} (lb)	F_{max} (lb)	F_b (lb)	Progressivity Ratio	$I_{0\text{-}0}$ (lb-sec)	$I_{sp}(0\text{-}0)$ (lb-sec/lb)	$\bar{P}_{tunnel}$ (psia)
20°F MOTOR TEMPERATURE																			
PFRT-1	2808-R2-92A	5/27	0.2901	0.495	0.9503	0.0452	0.0430	0.006	0.013	1.054	0.099	0.4696	56.63	75.62	69.29	1.335	74.64	257.3	0.0212
PFRT-2	2808-R2-40C	5/30	0.2950	0.497	0.9503	0.0452	0.0430	0.004	0.008	1.077	0.093	0.4615	63.28	76.72	69.10	1.212	75.97	257.5	0.0178
77°F MOTOR TEMPERATURE																			
PFRT-3	2808-R2-37D	5/27	0.2899	0.496	0.9503	0.0452	0.0436	0.006	0.018	1.034	0.077	0.4792	70.59	76.79	70.98	1.088	74.88	258.3	0.0199
PFRT-4	2808-R2-100D	5/30	0.2952	0.500	0.9503	0.0452	0.0451	0.006	0.011	1.051	0.089	0.4757	64.05	77.48	71.28	1.210	76.14	257.9	0.0166
PFRT-5	2808-R2-100A	5/30	0.2952	0.500	0.9503	0.0452	0.0449	0.005	0.010	1.049	0.077	0.4766	76.92	77.90	71.53	1.013	76.21	258.2	0.0169
PFRT-6	2808-R2-62B	5/30	0.2952	0.499	0.9503	0.0452	0.0442	0.005	0.011	1.054	0.098	0.4734	77.73	77.38	71.17	0.995	76.29	258.4	0.0175
PFRT-7	2808-R2-100C	5/30	0.2950	0.499	0.9503	0.0452	0.0437	0.006	0.013	1.053	0.067	0.4739	76.88	79.34	71.06	1.032	76.01	257.7	0.0177
PFRT-8	2808-R2-93C	5/30	0.2943	0.499	0.9503	0.0452	0.0426	0.004	0.011	1.044	0.087	0.4780	66.72	80.82	68.88	1.211	75.88	257.8	0.0174
PFRT-9	2808-R2-95B	5/30	0.2952	0.500	0.9503	0.0452	0.0441	0.004	0.007	1.046	0.075	0.4780	66.39	77.54	71.61	1.168	76.21	258.2	0.0182
130°F MOTOR TEMPERATURE																			
PFRT-10	2808-R2-95D	5/30	0.2954	0.500	0.9503	0.0452	0.0431	0.005	0.008	1.009	0.078	0.4955	71.02	80.88	74.60	1.139	76.57	259.2	0.0171
PFRT-11	2808-R2-87C	5/30	0.2959	0.499	0.9503	0.0452	0.0445	0.006	0.012	1.012	0.092	0.4931	74.63	81.20	74.58	1.088	76.70	259.2	0.0164
PFRT-Q-12	2808-R2-36C	5/26	0.2934	0.495	0.9503	0.0452	0.0441	0.004	0.016	1.015	0.081	0.4877	69.72	80.05	73.07	1.150	75.54	257.5	0.0204
PFRT-Q-13	2808-R2-40B	5/26	0.2954	0.500	0.9503	0.0452	0.0449	0.005	0.010	1.007	0.073	0.4965	87.16	79.42	74.31	0.911	76.23	258.1	0.0201
PFRT-Q-14	2808-R2-36D	5/26	0.2930	0.495	0.9503	0.0452	0.0433	0.006	0.011	1.002	0.080	0.4935	65.86	83.29	74.16	1.265	75.59	258.0	0.0197
PFRT-Q-15	2808-R2-36A	5/26	0.2937	0.495	0.9503	0.0452	0.0441	0.005	0.013	1.005	0.072	0.4925	74.57	80.06	74.00	1.073	7588	258.4	0.0220

5281

Table VII. Case Skin Temperatures from Development Firings.

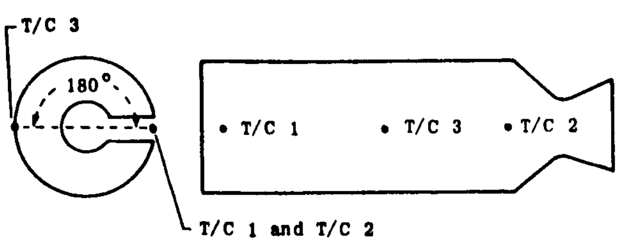
AR5284

Motor Number	Motor Temperature (°F)	Time	Case Temperature (°F)		
			T/C 1	T/C 2	T/C 3
LTV-4	20	Ignition	57	71	68
		Web Burnout	57	71	123
		3.3 sec.	61	75	227
LTV-6	20	Ignition	57	64	54
		Web Burnout	57	68	75
		9.8 sec	92	68	147
LTV-1	77	Ignition	71	71	71
		Web Burnout	71	75	75
		20.0 sec	102	85	133
LTV-2[1]	77	Ignition	70	70	70
		0.423 sec*	1005	147	73
LTV-3[2]	77	Ignition	73	73	73
		0.568 sec*	288	258	73
LTV-7	130	Ignition	82	64	85
		Web Burnout	82	64	85
		18.5 sec	92	85	137
LTV-8	130	Ignition	78	64	78
		Web Burnout	82	64	85
		15.9 sec	92	120	157
LTV-9	130	Ignition	78	64	78
		Web Burnout	78	68	82
		20.0 sec	92	85	109

* Time of Failure

Thermocouple Locations

Motors LTV-2,3



Motors LTV 1,4,5,6,7,8,9

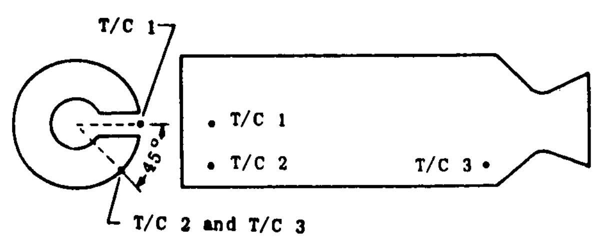


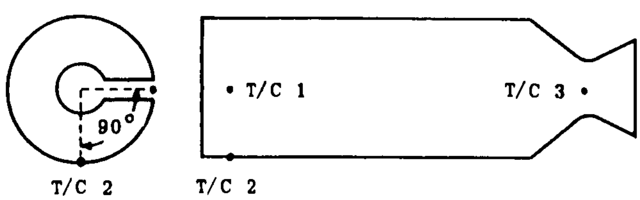
Table VIII. Case Skin Temperatures from Preflight Rating Firings.

5283

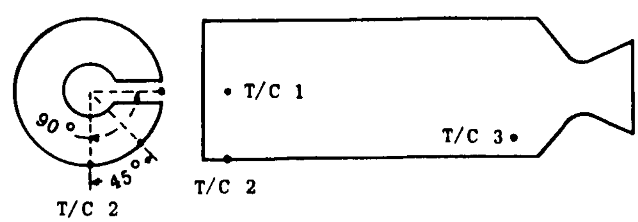
Motor Number	Motor Temperature (°F)	Time	Case Temperature (°F)		
			T/C 1	T/C 2	T/C 3
PFRT-1	20	Ignition	71	85	85
		Web Burnout	71	85	88
		26.2 sec	88	109	257
PFRT-3	77	Ignition	92	88	102
		Web Burnout	99	102	106
		23.5 sec	140	153	377
PFRT Q-12	130	Ignition	102	102	92
		Web Burnout	106	102	113
		2.1 sec	113	106	153
PFRT Q-13	130	Ignition	109	106	109
		Web Burnout	109	113	133
		23.7 sec	140	164	458
PFRT Q-14	130	Ignition	106	102	110
		Web Burnout	126	102	157
		14.7 sec	150	140	458
PFRT Q-15	130	Ignition	109	106	116
		Web Burnout	120	106	116
		22.1 sec	170	160	374

Thermocouple Locations

Motors PFRT -1,3



Motors PFRT Q-12,13,14,14&15



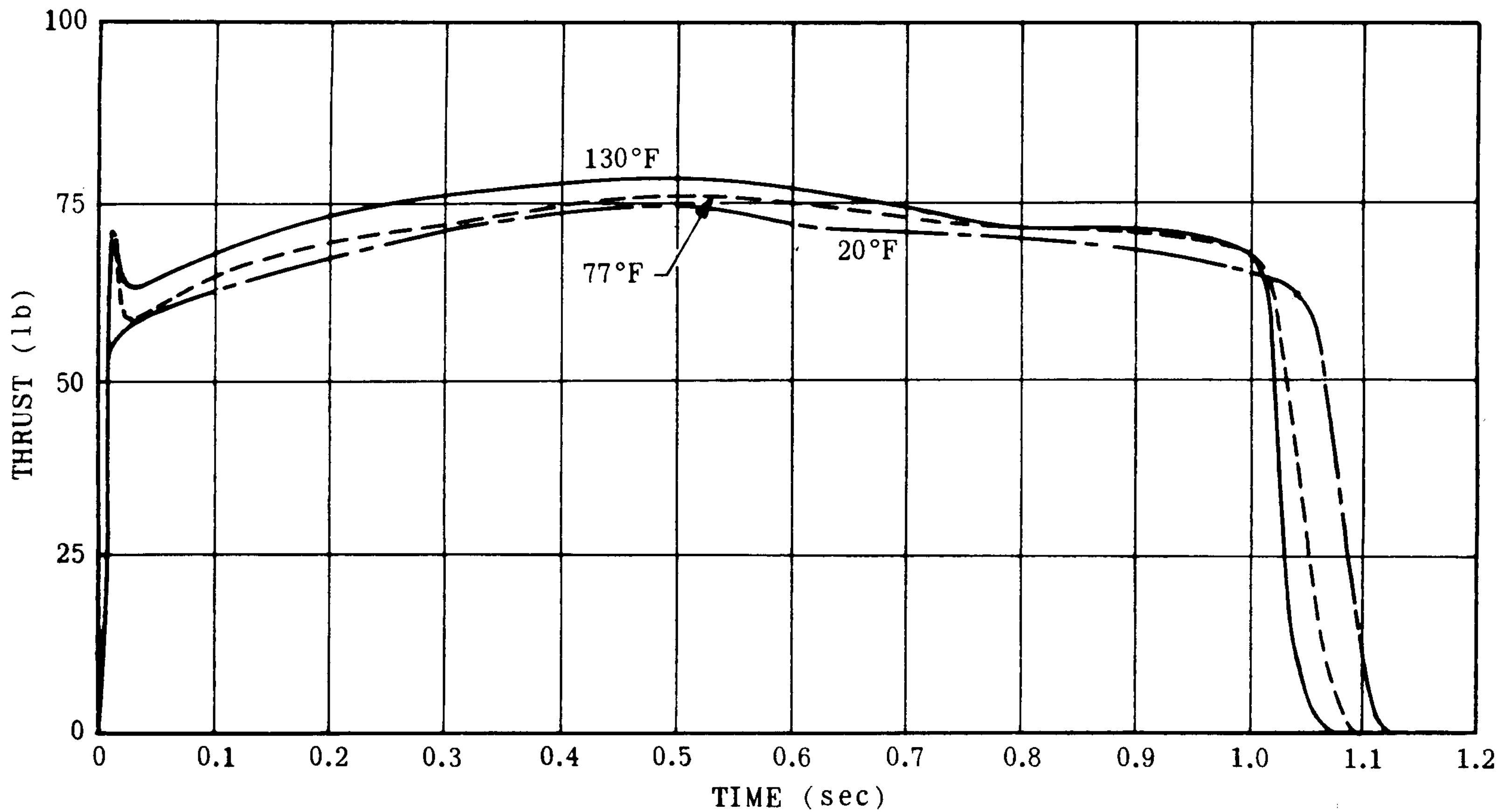


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Figure 12. Typical Thrust-Time Traces from MARC 36A1 Motors Fired at Simulated High-Altitude.

Both this change and the addition of the grain slot insulator were evaluated in heavywall motor firings LTVD-33, -34, and -35 and in flightweight motor firings X-1, -5, and -6. Test results verified the acceptability of both changes. All six ignition peak values were less than the specification maximum of 70 pounds at 77°F. Ignition thrusts in the three 130°F heavywall firings were 61.08, 61.92, and 64.13 pounds. In the X-Series tests, an ignition thrust of 59.68 pounds was measured at 20°F, and values of 68.73 and 61.12 pounds were obtained at 130°F. Flightweight case skin temperatures in the area over the grain slot were also significantly less than in LTV-2 and -3.

Inspection of motors X-1 and X-5 after test revealed that the nozzle exit cones had burned through. (See Figure 13.) These cases were known not to have been machined properly. As a result, the wall thickness in the burn-through area was undersize. Corrective steps were taken by the hardware manufacturer to insure that subsequent cases conformed to drawing tolerances. The burn-through had no apparent effect on motor performance in either firing. To prevent a similar failure in motor X-6, a copper pillow block was placed around the nozzle to serve as a heat sink.

Following confirmation of the design changes described above, the flightweight development program was resumed. Six of the seven remaining motors performed normally, yielding acceptable ballistic data. The seventh motor, LTV-5, failed to ignite after its squib functioned normally. Post-test examination of the igniter clearly showed that no 2M pellets had been loaded into the charge chamber. The chamber contained neither pellets nor residue and showed no signs of internal burning. Further, in firing LTV-5, the ignition current had been applied only to one squib. The heat generated by combustion of the pellets, if there had been any, would most certainly have cooked-off the second squib. However, this squib was recovered intact. Inspection surveillance of the pellet loading procedure was intensified to insure that the error was not repeated.

All 15 PFRT motors ignited and burned full duration without incident. Ballistic data were within specification limits except for

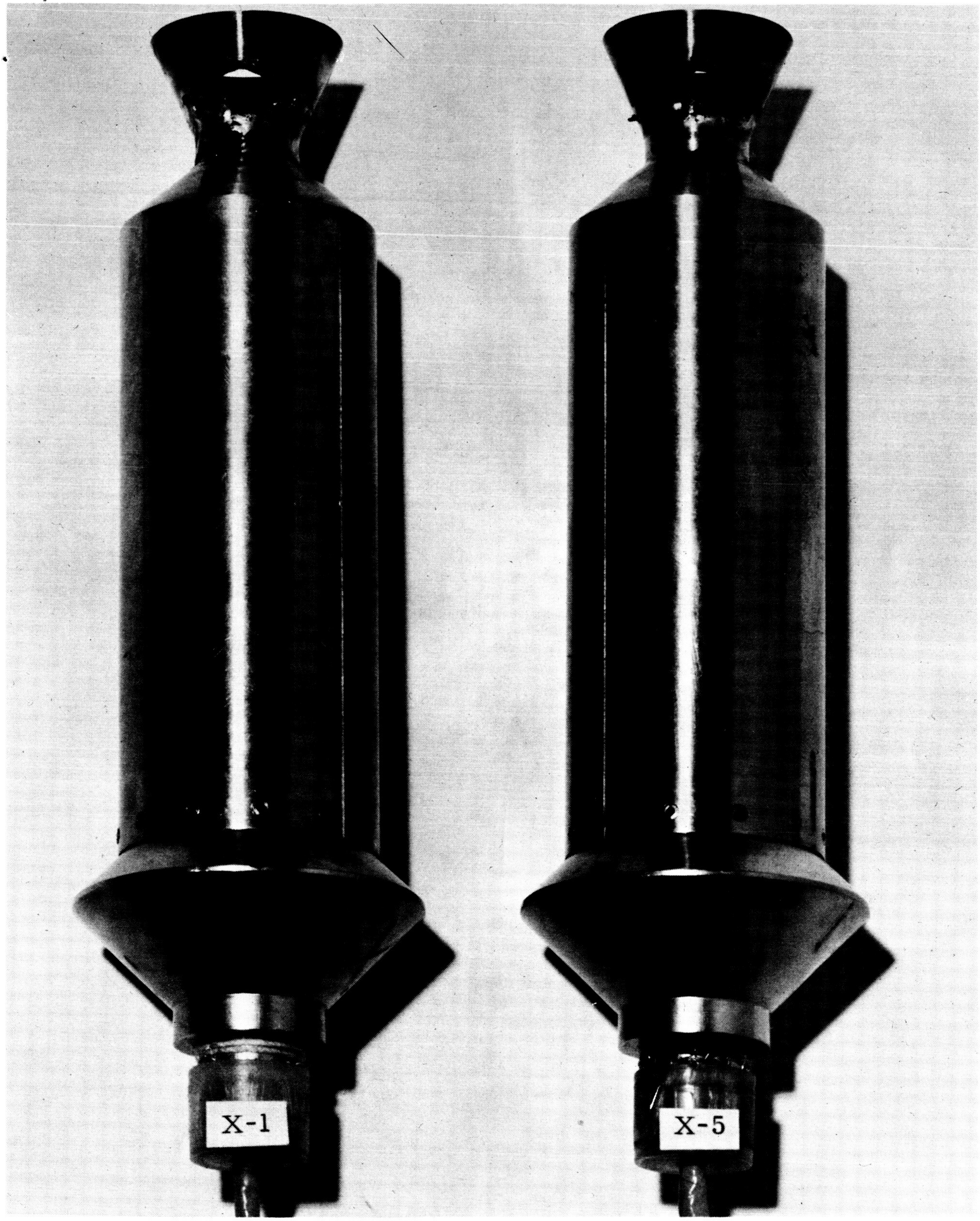

Figure 13. Expended Flightweight Motor Cases with Burned Through Thin-Walled Nozzles.

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(1) low impulses in two motors with discrepant, lightweight grains, and (2) high ignition thrusts in four PFRT firings.

Propellant weights in PFRT-1 and -3 were 131.6 and 131.5 grams, respectively. The minimum allowable propellant weight is 132.0 grams. Ling-Temco-Vought, however, had waived the two motors to permit their use as backup environmental test units. The lightweight grains resulted in total delivered impulses of 74.64 and 74.88 pound-seconds, values slightly below the minimum limit of 75 pound-seconds.

Specification 304-411 stipulates that all flightweight and PFRT motors be fired with their nozzles vented to a simulated high-altitude atmosphere. Nozzle closures were thus omitted from all PFRT motors except PFRT-4, -5, and -6. Closures were included in these units to obtain ignition transient data for comparison with equivalent data from motors without closures. Two of the four excessive ignition peaks were obtained in the firing of motors PFRT-5 and -6, both of which contained closures. The peaks in these firings were attributed to the increased initial pressure buildups caused by the closures. No definitive cause, however, could be determined for the excessive ignition values in PFRT-3 and -7. A contributing factor in PFRT-3 may have been that environmental testing of this unit had caused further granulation of the 2M ignition pellets, thus exposing more burning surface.

3.2 ENVIRONMENTAL TESTS

Flightweight motors were temperature conditioned for at least eight hours before test; heavywall motors for at least four hours. In addition, three of the flightweight development motors, LTV-1, LTV-4, and LTV-7, were thermal cycled before final temperature conditioning. Cycling consisted of three hours at each of the following temperatures in succession: 20°F, 130°F, 20°F, and 130°F. After final conditioning, each motor was transported to the test facility in a sealed, thermally stable container. Maximum time between removal of a motor from the container and ignition was 10 minutes.

Before firing, six PFRT motors were subjected to environmental tests of vibration, shock, acceleration, and drop in accordance with LTV Specification 304-411. These tests were conducted at United Aerotest Laboratories, Inc., Deer Park, Long Island, New York. Four of the six units were specifically designated as qualification rounds; the other two, PFRT-1 and -3, contained discrepant propellant weights and were thus designated as backup motors. The environmental tests are described briefly below:

a. Acceleration - Each motor was accelerated at 3 g's for one minute along its longitudinal axis and at 25 g's for one minute along its transverse and normal axes.

b. Shock - Each motor was subjected to a shock of 30 to 35 g's for a duration of 11 plus or minus 1 millisecond. Three shocks, in each of three mutually perpendicular axes, were applied with the nozzle end down and three with the head end down. Total number of shocks for each unit was thus eighteen. A permanent record of the shock pulse wave form was made for each motor attitude.

c. Drop - Each motor was crated and dropped once in each of three mutually perpendicular axes. The motor was dropped on a hard concrete surface from a height of 36 inches.

d. Vibration - Each rocket motor was first subjected to sinusoidal vibration as follows:

Axis	Frequency (cps)	Amplitude
Transverse and normal	5-10	0.4 inch d.a.
	10-50	2.0 g's
	50-500	9.0 g's
	500-2000	18.0 g's
Longitudinal	5-10	0.2 inch d.a.
	10-50	1.0 g's
	50-500	2.0 g's
	500-2000	4.0 g's

For each axis, the motor was vibrated in a sinusoidal logarithmic sweep of 2.0 octaves/minute from 5 to 2000 cps. The vibration was monitored with one filtered control accelerometer.

After sinusoidal vibration, each motor was subjected to random vibration consisting of white gaussian noise of 0.07 g^2/cps for 4 minutes from 20 to 2000 cps. The motors were vibrated along each of three mutually perpendicular axes. Before testing in any axis, the spectrum was equalized, and a short run recorded on tape. The tape was then analyzed, and the results displayed on an X-Y plotter. One control accelerometer was also used in these tests.

Visual and radiographic inspection of the six motors disclosed no evidence of physical damage or other detrimental effects as a result of the environmental tests. Squib resistances, measured before and after each test, were found to be within the tolerance limits of 0.65 and 1.00 ohm.

4. RELIABILITY AND DOCUMENTATION REVIEW

4.1 RELIABILITY REVIEW

The design of the MARC 36A1 rocket motor was subjected to a reliability review before initial release of manufacturing drawings. Items covered included:

a. Parts and materials -- their selection, application, and definition

b. Tolerances and dimensioning

c. Stresses and environmental safety margins

d. Producibility and value analyses

e. Human factors

Reliability comments on these items were submitted to program management, design engineering, and process engineering at a design review meeting on March 17 and 18, 1965. Agreement was reached on several changes providing for: (1) a clearer definition of desired characteristics; (2) further investigation of case corrosion - resistance treatment; (3) testing of igniter body-to-case pinning.

4.2 RELIABILITY SURVEILLANCE

Manufacture of the propellant extrusion die and subsequent test extrusions were conducted under reliability surveillance. Corrective actions were effected to ensure that dimensional tolerances were maintained. These included Quality Control inspection of dies, as well as first-article inspections of extruded grains.

Initial igniter assembly operations were monitored to assure compliance with reliability provisions. Final assembly and static firing of the nine flightweight development motors and the 15 PFRT motors were witnessed by a Government Inspector and an Atlantic Research Reliability Coordinator.

4.3 RELIABILITY DOCUMENTATION

Reliability documentation issued during the program included:

a. Reliability Program Plan

b. Quality Program Plan

c. Reliability Requirement sheets for use in inspecting purchased and manufactured parts

d. Manufacturing and Inspection Flow Chart showing the applicable process, inspection, and test documents at logical points in the production sequence

e. Failure Modes, Effects, and Criticality Analysis

f. Reliability Assessment indicating 90 per cent reliability with 90 per cent confidence for motor performance

g. Motor Log Books for the ten delivery units

h. Motor Folder Summaries

4.4 DESIGN AND PERFORMANCE DOCUMENTATION

In addition to the above reliability documentation, the following were issued covering motor design and performance:

a. General Arrangement Drawing

b. Performance Manual

c. Stress Analysis Report

d. Engineering and Fabrication Drawings

e. Test Specifications and Procedures

f. Material Specification List

g. Status List of Specifications and Qualification for Parts and Materials

h. General Process and Procedures Manual

i. Parts List

j. Manufacturing Equipment Description List

k. Model Specification

l. Handbook of Description, Operation, Maintenance, and Handling Instructions

5. CONCLUSIONS AND RECOMMENDATIONS

The MARC 36A1 rocket motor described in this report has been accepted for service use by Ling-Temco-Vought, Inc. After review of Qualification and PFRT results[1], LTV authorized the delivery of ten flightweight motors. Three were shipped on June 3, 1965, to LTV in Dallas, Texas, for evaluation. The remaining seven were shipped to Vandenburg Air Force Base, California, on June 15, 1965.

Although the current motor is acceptable, a review of the design before further production would be of value. Motor design and fabrication could be simplified by taking advantage of recently relaxed envelope constraints. Anticipated changes are expected to result in lower production costs.

1. "Development, Qualification, and Preflight Rating Testing of the MARC 36A1, 1-KS-75 Spin Motor for the Scout Vehicles" (Unclassified Title), Atlantic Research Corporation, June 1965, Report Number TR-PL-8193 (CONFIDENTIAL report).

GLOSSARY OF BALLISTIC TERMS

Zero Time,	Time of current application
Ignition Delay, t_d	Time from 0 to 10 per cent F_{max}
Ignition Time, t_i	Time from 0 to 75 per cent F_{max}
Burn Time, t_b	Time from first indication of thrust to web burnout
Tailoff Time, $t_{tailoff}$	Time from web burnout to zero thrust
Burning Rate, $\bar{r}$	t_b/web
Ignition Pressure, P_{ign}	Peak of initial pressure rise
Maximum Pressure, P_{max}	Highest pressure excluding ignition
Average Pressure, P_b	$\int_{t_b} Pdt/t_b$
Ignition Thrust, F_{ign}	Maximum thrust during ignition
Maximum Thrust, F_{max}	Highest thrust excluding ignition
Average Thrust, F_b	$\int_{t_b} Fdt/t_b$
Progressivity Ratio	F_{max}/F_{ign}
Total Impulse, I_{0-0}	$\int_0^0 Fdt$
Specific Impulse, I_{sp}	I_{0-0}/W_P (Propellant Weight)
Discharge Coefficient, C_D	$W_P/\bar{A}_t \int_0^0 Pdt$
Characteristic Exhaust Velocity, C*	$\frac{\bar{A}_t g}{W_p} \int_0^0 Pdt$